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ABSTRACT

Although computers have been used in education for 20 years in the United States and Europe, they have not been widely used in the less developed countries of the world because the initial investment and operational costs of computers have been too high. Should advances in hardware technology continue to reduce such costs, some educational applications of computers will soon be affordable to less developed countries. In this paper, the current status of educational applications of computers is reviewed with a view toward predicting the direction of such applications in developing nations. An overview of the development and use of computers from the 1950s to the present is provided, and hardware and financial factors influencing the development of educational software are discussed, as well as classification and design principles relating to these programs. Potential problems in using computers in developing nations are described, including (1) the environment; (2) power requirements; (3) lack of human resources; (4) curriculum and pedagogy; (5) high costs of both the initial investment in computers and their operation; and (6) the developmental quality of courseware. Specific areas in which computer-assisted instruction may prove to be cost-effective for developing countries are suggested, and a glossary is included. (Author/MES)

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CLASSROOM USES OF THE COMPUTER:
A RETROSPECTIVE VIEW WITH IMPLICATIONS FOR DEVELOPING COUNTRIES

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November 1985

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Abstract

Although computers have been used in education for 20 years in the United States and Europe, they have not been widely used in the less developed countries of the world because the initial investment and operational costs of computers have been too high. However, recent advances in hardware technology are reducing the costs considerably. Should this trend continue, some educational applications of computers will soon be affordable in LDCs. In this paper, the current status of educational applications of computers is reviewed with a view toward predicting the direction of such applications in LDCs.

Although computers have been used in education for 20 years in the United States and in Europe, this technology has not been widely used in the less developed countries of the world. The main reason is cost: both the initial investment and the operational costs of computers have been too high for most LDC's. However, recent advances in the hardware technology are reducing the costs considerably. Should the current trend continue, some educational applications of computers will become affordable in the less developed countries in the near future. In this paper, the current status of educational applications of computers is reviewed with a view toward predicting the direction of such applications in LDC'S.

Computers can be used in education in a number of ways: for administrative purposes, for information retrieval, for direct instruction, and for simulations. The use of computers in educational administration is already spreading throughout the world, and there is no reason to doubt that this trend will continue; computers are being used in many Ministries of Education for keeping student records, for statistical analysis, and for ordinary bookkeeping functions such as payroll calculations. Administrative applications are usually implemented on centrally located computing facilities, sometimes shared with

other government agencies. Such applications may improve the cost-effectiveness of the educational system of a country by increasing the efficiency of the educational bureaucracy or by enabling it to perform tasks such as statistical analyses that could not otherwise be undertaken. Information retrieval may be used primarily by the administration, or it may be used more directly by students as a quasi-library facility. In the following, the concern is not with such indirect uses of the computer in education, but rather with the direct teaching applications, in which students interact with the computer without intermediaries, for the express purpose of increasing their knowledge or skills in some school subject. The programs may take the form of interactive instruction, in which the computer plays the role of teacher, or the form of a simulation, which is a tool to be used as an adjunct to more conventional instruction.

The potential of the computer as a private tutor was first recognized soon after the first large commercial computers became available. The power of the computer to make instantaneous decisions based on large quantities of detailed information enable it to deal with students in a highly individualized way; by keeping accurate records of the student's interests, aptitudes, knowledge, and skills the computer can react to each student differently, providing instruction that is highly sensitive to individual differences. Because of this ability to adapt to individual needs, the instruction can be more efficient than large group instruction. With the computer, no student will waste time by waiting until others in the class have

finally grasped a concept that was immediately clear to him; neither will any student struggle vainly to keep up with a class that is progressing faster than he can manage. Nor will the pace of instruction be constant for a given student; instead the pace can vary both by topic and by student so that a student may proceed rapidly through material that he grasps readily, and more slowly in topics for which he is less well prepared or for which he has less natural aptitude.

Although this ideal has long been clear in the minds of the materials developers, the realization of it has come slowly. To understand the complex interactions between hardware and software, and the continuing influence of cost constraints on the directions of research and development of computer-based instruction over the last 20 years, some understanding of the history of development of both hardware and software is needed.

Mainframe computers, minicomputers, and microcomputers

It was in the 1950's that the commercial use of computers became wide-spread. Although the machines were not large by today's standards, they were expensive; costs were so high that, to reduce the cost per hour, most computers were operated continuously day and night, seven days per week. The standard mode of operation was batch processing, with programs and data fed into the computer by means of punched cards. The computer performed only one task at a time, but it did so at speeds that humans found incredible. The concept of an "interactive"

program, in which the computer would interact with a human, was conceived in the 50's but generally not implemented because it was not cost-effective to slow down the enormously expensive machine to the speed with which a human could work.

It was only with the advent of the time-sharing operating system, in about 1960, that interactive programs became possible. Within only a few years, interactive programming languages, like BASIC, were developed, as were primitive precursors of today's word processing programs. The time-sharing systems which made these programs possible allowed a number of people, each using his own terminal, simultaneous access to the computer; the method used was a "round robin," in which the computer would serve each person in turn for an instant before going on to the next person; because of the speed with which the computer worked, it appeared to each person that he had sole use of the computer. (This, at least, was the ideal; in practice, too many simultaneous users, operating programs that required a great deal of computer time, could slow even the fastest computers to the point where the time necessary to complete the round robin became noticeable to all.)

With the advent of time-sharing, computer-based instruction became feasible, and the first instructional programs were implemented in the early 60's, shortly after time-sharing systems became available commercially. At that time, students were expected to go to the computer; terminals were located at most a few hundred feet from the physical computer. By the mid 60's, remote terminals became more common; students worked at

terminals located at hundreds or even thousands of miles from the computer, with communication by means of telephone lines. In some cases there were dedicated telephone lines, so that remote terminals could have 24-hour access to the computer. Some computers could handle a hundred or more such remote terminals. The costs of telephone service were quite high so a system of sharing telephone lines was developed, with each line serving many terminals. A common installation might contain 8 to 16 terminals, all sharing one telephone line to the distant computer.

Even with shared telephone lines, the cost of telecommunications was great, and the newly developed minicomputer was rapidly embraced for educational programs; since minicomputers were inexpensive enough to be used with only a dozen terminals, they could be located at the terminal site, thereby eliminating telephone costs. Minicomputers, like mainframe computers, use a time-sharing system, so that a number of people can simultaneously use the computer; from a functional point of view the important differences between mainframe computers and minicomputers are the cost and the number of people who can have simultaneous access, with the less expensive minicomputers serving fewer people.

The move from mainframe computers to minicomputers was part of a historical cycle: at first, computers handled only one task at a time, then there was a trend toward connecting more and more terminals to each computer so as to share the cost of the computer over more users; as the terminals increased in number

and moved further and further away from the computer, the cost of telecommunications increased and there was then a reactionary trend to use smaller and less expensive computers which could serve fewer people but which did not entail extravagant telephone line costs.

This cycle reached its extreme with development of the microcomputer, which is usually used by one person at a time. The main reason for the swing back to single users is that the microcomputer is so inexpensive that a personal computer for each user is cheaper than sharing the facilities of a larger, more expensive machine. Although the cost of a microcomputer is substantially less than a share of the cost of a larger computer, there is a concomitant decrease in power; even though microcomputers can perform many of the tasks that could once only be performed on large mainframe computers, the mainframes of today are much larger and more powerful than their ancestors, and the gap in power between microcomputers and large mainframes is enormous; this difference in power has had a large effect on the nature of the educational programs implemented on the two different kinds of machines, as we shall see below. Interestingly, the cycle from single user systems to multiuser systems to single user systems is now beginning to swing back again toward multiuser systems; the 16-bit microcomputers, which are more powerful than the older 8-bit microcomputers, can be operated under time-sharing systems similar to those used on mainframe computers. Depending upon the configuration of the system, microcomputers can operate with a dozen or more terminals and other peripheral devices; these larger microcomputer

systems are functionally equivalent to minicomputers and to the smaller mainframe computers of the past. The distinction between microcomputers and larger computers is becoming blurred from the individual user's point of view; the only distinction that promises to remain clear is between a personal computer and a shared system, be it a microcomputer or a mainframe.

The "power" of a computer system, mentioned above as a distinguishing characteristic between mainframes and microcomputers, has several attributes. One is the speed of the machine; another is the amount of storage space available. Both the speed and the storage space have several constituents, and there are interactions between speed and space. One constituent of speed, frequently the least important, is the speed of the central processing unit (CPU) of the computer; although the CPU is the heart of the computer, most of them are now so fast that, for educational purposes, slight differences in the speed of the CPU are unimportant. What is more important is the speed with which the computer can access data from remote storage devices, such as disks or diskettes. This is important in educational programs since most of the instructional messages would be stored as "data" on a disk. Even disk-access speed is not always a central issue since the apparent speed of the machine is frequently determined not by just the speed with which the disk is accessed but by the number of times it must be done, which is in turn influenced by the size of memory (where data and programs are stored temporarily as they are being used). Another consideration is the size of the program being used. Machines with very small memories cannot hold all of a large

program in memory at one time, and must store part of it on a disk; the program is thus executed in pieces with each piece brought into memory from the disk as it is needed. If a program is quite small and does not use much data, even the smallest microcomputer can run the program at incredible speeds. A medium-sized program might run much more slowly, while a very large program (if it could be run at all) might run so slowly that the human user would lose patience; the speed with which programs of varying size will execute on a small computer is not just in proportion to the size of the program--beyond a certain size the program will not run fast enough to be acceptable. In addition to its impact on apparent speed, storage space (primarily disk) may impose additional constraints: some of the large educational programs that have been implemented on mainframe computers will not fit into the storage available on the smaller microcomputers; this fact has greatly influenced the direction of educational software development in recent years.

Peripheral Hardware

Besides the computer and auxiliary storage devices, other "peripheral" hardware, such as display devices, has influenced the style and to some extent the content of educational programs. Two types of peripherals are of great importance in the design of instructional programs: output devices that allow the computer to communicate with the human user, and input devices that allow the human user to communicate with the computer.

The most usual output device in the 1960's was the typewriter terminal; in the 70's, video displays, which were at first very expensive, came into wider use, and now are the most common output devices. Both typewriter terminals and video can display printed words; most instructional programs in the past and at present communicate primarily by means of printed messages. And the most common input device is the keyboard so that the human user also communicates by means of the written word. Because these devices are so widely used, most instructional programs depend upon the student's ability to read and write.

Video displays, as everyone knows, are capable of doing more than just printing words. The screen can also be used for a display of pictures, even moving pictures. Although most video displays cannot show high quality pictures, the use of even simple illustrations can enhance instruction greatly in many subjects. In a few subjects, color can also enhance the educational quality of the program. Displays of pictures, especially pictures that move, require a great amount of compute power and disk storage space; for this reason, the programs that use graphic displays are usually quite limited in content and total instructional time.

Not all subject matter can be conveyed by means of pictures, so for students who are not completely literate, oral communication is more desirable. There are a variety of output devices that allow computers to talk. At the present time all

of these devices have some disadvantages, either the storage space required, the low quality of the speech, or the cost of the device, but great progress is being made with synthesized and digitized speech, and there is much interest among educational programmers in such devices. There are perhaps hundreds of educational programs now available that use audio output. These programs are not all aimed at young non-readers or other illiterates; many educational topics, such as music and foreign languages, are best taught with audio output even for literate students.

The other side of the coin, the ability to input (and understand) human speech, lags considerably behind auditory output, although even in this, there have been significant advances in the last few years. It will not be long before there will be effective, commercially available educational programs that will not only talk to their students, but will also listen to their spoken answers.

Factors Influencing the Design of Educational Programs

The development of educational programs for computers has been influenced over the last 20 years by a number of factors, many of them related to the kind of hardware available. One of the most important factors has been the size and power of the computer used. The kind of programs that were developed in the 1960's for mainframe computers were usually much larger (in terms of educational content and complexity of the devices used

for individualizing the instruction) than programs that are being developed today for the smaller and less powerful microcomputers. Another factor that has greatly influenced the direction of development has been the availability of diverse devices for communications; many recent programs use color graphics, animation, and sound effects.

Hardware has not been the only factor influencing the development of educational software. Another non-trivial factor is the amount of development money available. In the 1960's there was a fairly large amount of research and development money awarded by various funding agencies; as a result large programs, which are costly to develop and test, could be produced. In the 1970's this source of funding was considerably reduced; as a consequence, recently developed programs are usually funded privately, and because there is no large commercial market for educational programs, are consequently smaller in scope.

Another financial factor has been the cost of the equipment; with the advent of the microcomputer at its relatively low cost, there has been an increase in the number of small efforts in educational development. It is no longer necessary to invest millions of dollars in equipment before development can start; almost any interested person can purchase a microcomputer and write educational programs. There are now hundreds of small developers of educational programs, many of them teachers working in their spare time.

The attitude of the buyers of educational programs has also changed. In the very early 60's, there was great concern with the quality of education, especially in mathematics and the sciences. During the 70's this interest waned, and there was more concern with the relevance of education and with the motivation of students. In recent years, there has been some interest in "basic skills," but the concern with motivation continues.

The result of all of these influences is a change in the flavor of educational programs over the last twenty years. There have been two main streams of development work. The earlier one started in the 1960's with the production of very large programs for mainframe computers. The concern was with providing instruction that could be used within the framework of the conventional school system. The programs were designed to be used as a part of the ongoing instruction, with students receiving some part of their daily instruction from the computer. Computer laboratories, containing dozens of student stations, were built in schools, and students came to the laboratory regularly. There was a great effort to integrate the content of the computer-assisted instruction with the teaching that took place in the classrooms. Teachers were not always intimately concerned with the operation of the computer laboratory, but they were kept well-informed of their students' progress and allowed to make decisions about the placement of their students in the computerized courses. Many of the computer-assisted courses available then could supply months or even years of instructions. With a few notable exceptions, the

instruction was highly verbal; messages were delivered to students by means of printed words, and the students responded by typing on a keyboard.

The second stream of development work had its roots in some of the programs developed for mainframe computers in the 1960's but did not come into full flower until the late 70's and early 80's when microcomputers became more widely available. This stream of computer-based instruction consists of smaller programs, with more emphasis on motivation of the student than on cognitive concerns. The programs often use sound effects and graphics, frequently in color, sometimes in motion; these programs are generally more appealing at first glance than the older programs. In general, however, there is also an accompanying paucity of content; many programs contain only enough material to occupy a student usefully for a half hour or an hour, perhaps in five or six ten-minute sessions. The pedagogical value of the new, smaller programs is, in some cases, extremely low. This is not to say that all of the earlier mainframe programs were pedagogically sound, or that all of the later microcomputer programs are not; I am only pointing out a tendency to sacrifice pedagogy to motivational qualities. In any case, it is very difficult to make a reasoned judgment about the relative effectiveness of the newer microcomputer programs since so few of them have been adequately evaluated.

Another tendency in the design of the smaller, new programs is that the decision about what content to include is based more on the capabilities of the machine than on the needs of the

students. In some ways, this is a good thing; some of the older, more comprehensive programs did not adequately take into account the constraints of the medium; in their effort to provide complete courses of instruction, they sometimes included topics that would better have been taught by the classroom teacher. In other ways, it is not desirable to let the medium determine the instructional content; we may end by teaching only those things that are easy to teach.

The explicit goal of computer-based instruction has been to provide individualized instruction. But there has been a continuing discussion for years on exactly how this should be done; one of the areas of most disagreement has been in the way decisions about the sequence of instruction are to be made. Some designers feel that the control should be in the hands of the student (or teacher), while others feel that it is the duty of the program designer to provide mechanisms which will collect and analyze response data from the student in order to make optimal automatic decisions about the sequence of instruction. The arguments have to do with the ability of the student to make rational decisions in the face of content that he does not yet know, the desirability of allowing the student control over his own destiny, the power of the computer in taking into account many variables simultaneously, the inability of the computer to consider more subtle factors (most programs do not, for instance, have detailed information on the student's interests, and certainly do not know his mood of the day), the motivational value of involving the student in decisions, and so on. It is probable that the best solution lies somewhere between the views

taken by extremists on either side of this argument; it could be argued that "strategic" decisions should be made by the student, who is often in the best position to know his global goals, while "tactical" decisions are made automatically by a well-designed instructional program that knows the most efficient way to reach those goals. In general, the tendency of the larger mainframe programs has been to take over the decision making, while the tendency in the microcomputer programs is to leave the decisions to the students. In many microcomputer programs, this means that the program designer has abandoned the responsibility for sequencing the material; some of the simpler microcomputer programs, for instance, offer the student a choice between "easy," "medium," and "difficult," without any indication of the meaning of these terms in the context of the subject matter, and offering no advice to the student on how to make a rational decision.

Classification of Educational Programs

The computer-based educational programs that have been developed cannot be categorized easily. Traditionally, programs that emulate a teacher have been divided into "tutorial" programs and "drill-and-practice" programs; although the concept has some meaning, the distinction is not always precise, for tutorial programs can, and usually do, contain a practice component while drill programs may contain remedial sequences of instruction that are clearly tutorial in nature. There is also some evidence to show that skillfully designed drill programs

can promote conceptual learning by providing the kind of environment that allows students to abstract general principles from the exercises given; this kind of "guided discovery" teaching can be quite effective for certain topics.

Another way of classifying programs is by whether they are intended as supplementary to some other ongoing instruction. Drill programs that deliver something like "flash card" drills in spelling, arithmetic, chemical formulas, and so on, are generally of greatest use in conjunction with other instruction in language arts, mathematics, chemistry, and so on. Some tutorial programs were designed as completely self-contained courses, not requiring the support of a knowledgeable teacher; there have been programs that teach foreign languages, physics, symbolic logic, computer programming, and many other subjects, to students who do not have access to other means of instruction. Self-contained courses have generally been written for adults, while supplementary drill programs have generally been written for school children.

A third way of classifying programs is by the locus of initiative. In the traditional tutorial and drill programs, the initiative is taken by the computer. Although the program may ask the student to choose the topic or the level of difficulty, once that global decision has been made, the instruction is presented by the computer and the student is expected to answer responsively. In contrast, in simulation programs the initiative is with the student; the student starts the dialogue, and directs it as it continues. In a simulation of electrical

circuits, for example, the student designs the circuit, specifying the resistance, voltage, reactance, and so on of the various devices to be incorporated in the circuit, while the role of the computer is to demonstrate the action of the completed circuit. There are a large variety of simulation programs, and they are potentially a means of revolutionizing the teaching of some subjects. At this time, very few evaluations of the educational effectiveness of simulation programs have been undertaken. One open question about simulations is how well students will transfer what they have learned to real situations, especially from simulations that are highly verbal; many simulation programs do not illustrate or model a real situation; they simply describe the results in words, and it is not known if students perceive these results as having a strong relationship to reality, or if they are viewed as being solely theoretical or, even worse, fantasized. Some of the simulation programs that have been developed are quite realistic imitations of the real world; there have been dental and surgical simulators that use constructed models of human bodies that exhibit human reactions to drugs, blood loss, etc.; flight and driving simulators operated under computer control can also be quite realistic. Between the two extremes of programs that use realistic models and those that rely entirely on verbal descriptions, there are a number of simulation programs that show physical phenomena pictorially; there are, for instance, programs that show projectile trajectories under varying conditions of thrust, angle, and gravity. There are also programs that demonstrate the actions of pendulums, the reflection and refraction of light, chemical reactions, the operation of internal combustion engines, and so

on. Many simulation programs have been designed for non-educational purposes, some serious (stress on bridges under varying conditions of wind, population dynamics), some more playful (video arcade games). Under the right circumstances, even these programs that have not been designed for educational ends can be used for teaching purposes.

In some sense, programs like word processors and data base managers can be considered to be simulators of typewriters and office filing systems, and these programs can certainly be used for educational purposes even though that was not the original intent. Perhaps a happier description of these programs would be as "tools," which then becomes another classification--along with tutorial programs, drill programs, and simulations--of the kinds of programs that can be used in education.

A fifth kind of program that has been used in education is the beginner's programming language; LOGO, BASIC, and Small Talk, for instance, were all designed as programming languages for beginners, to teach the fundamental concepts of programming in a simple--and fun--environment. This class of programs is quite different from the previously mentioned categories because the primary objective is not to teach traditional subjects in a more effective way but rather to introduce an entirely new subject into the school curriculum. The advocates of teaching programming to school children are quite vocal, and sometimes promise more than they can deliver; LOGO and Small Talk aficionados are prone to promising that students will develop "thinking skills" that will find application far beyond the

actual subject matter that is taught. So far, the more extravagant claims have not been substantiated, but there is nevertheless a good argument for adding some kind of "computer literacy" to the school curriculum.

The Design Principles Used in Educational Programs

Not all computer-based instruction has proved to be effective enough to warrant the high cost of implementing it, but there are certain programs that have been adequately evaluated and proved to be effective adjuncts to the school instructional programs. There are also many programs that appear to be very effective, but that have not yet been evaluated in a precise enough way to allow the conclusion that they are indeed cost-effective.

What, then, are the attributes of the successful programs, and what explicit guiding principles were used in their development?

One absolutely undisputed advantage of the computer over other media of instruction is the ability of the computer to deliver immediate and specific feedback to the student with each response that he makes. Immediate reinforcement of response is a principle that is embodied in all programs, and is perhaps the only reason for the success of some. The power of this device is frequently not given the credit it is due; because it is widely known and widely applied it is treated with the familiar-

ity of an old hat. There are those who would argue that graphic illustrations can be delivered better by video tape, that printed material is best produced in book form, and that foreign language instruction is best given by a native speaker of the language, and that therefore computer-assisted instruction that depends on low-resolution graphics, screens full of printed material, and synthesized speech of questionable quality is doomed to failure. These people are overlooking the enormous advantage of immediate feedback and its ability to compensate for many other seeming inadequacies.

Another principle that is used in the design of many, but not all, educational programs is the individualized sequencing of instruction. This principle was more widely applied in the older programs implemented on mainframe and minicomputers than it is in the flashier programs implemented on microcomputers, although even then the devices for individualizing the sequence were sometimes quite naive. This is not to say that the branching strategies used by some programs were not complex; they were sometimes incredibly elaborate. However, our ability to program elaborate branching strategies is far ahead of our knowledge of how to design educationally appropriate branching procedures, so that many of the branching algorithms were more a chance for the programmer to demonstrate his brilliance in manipulating the medium than a chance for him to show a profound understanding of the characteristics and needs of his human audience. All this aside, however, even very simple branching strategies can sometimes contribute greatly to the efficiency of the instruction; pretesting students to determine if they should

skip over a section of tutorial instruction, for instance, can sometimes save significant amounts of the student's time.

The above-mentioned principles, immediate reinforcement and individualized sequencing of instruction, are the primary means by which computer-based instruction is individualized, and it is mainly these attributes of the instruction that make it more efficient than teaching by other means. Other attributes of the various kinds of teaching programs can frequently be achieved better in some other way. It is not the ability of the computer to show colored pictures nor its ability to synthesize human speech nor its ability to store quantities of textual material that gives it its power; it is the combination of these together with the ability to individualize the instruction that gives it its power and its promise.

Although all teaching programs use immediate reinforcement and many programs use individualized branching, the methods by which these two principles have been implemented have varied widely. Immediate reinforcement, for example, sometimes consists of no more than a message to the student informing him that his response was correct (or wrong). At the other extreme, a single incorrect response from the student is sometimes taken as a sign that a lengthy and elaborate explanation of the concept is called for. Devices for determining the sequence of instruction have an even broader range of possibilities. One reason for this variety is that we do not yet know enough about many aspects of human learning to devise the most appropriate reaction in a given situation. The programs simply do not

"know" enough about the individual student they are dealing with, nor about students in general, to make smart decisions. One encouraging trend is the basic research that is going on in artificial intelligence and cognitive science. Recent attention to the learning problems of young and to the design of "expert" systems may point the way to the development of teaching programs that are much more astute than any we have seen in the past.

Problems in Using Computers in Less Developed Countries

Having briefly reviewed some of the aspects of the development of computer hardware and educational software, I turn now to the question of applying these developments in the less developed countries of the world. When computers are used for education in the less developed countries, it is to be hoped that many of the mistakes made in the developed world will not be repeated there. And it is also to be hoped that the most recent developments in the technology can be immediately applied, so that the history of development of hardware and software will not be needlessly replicated in other countries. With adequate guidance, both of these pitfalls can be avoided.

Besides the limitations and problems mentioned above in the discussion of the history of educational computing in the United States, there are some additional constraints that are more pertinent to implementations in other countries, and that may stand in the way of rapid dissemination of the technology in the

developing world. The major constraints have to do with the environment, power requirements, human resources, curriculum and pedagogy, and finances, with financial concerns being closely related to other constraints.

The environmental concerns arise from the fact that computers are sensitive to heat, dust, humidity, vibration, and mechanical shock. Even in the United States, computers are often operated in controlled environments, with air conditioning and filtering; they are not often moved, and when they are, are moved with care. In many parts of many less developed countries, the environmental hazards are greater than in most parts of the United States; heat and dust are great problems in many places. Environmental constraints can be compensated for in two ways: the environment itself can be controlled by means of air conditioning, etc., or computers that are more resistant to environmental hazards can be purchased; such computers are available, having been developed for the Armed Forces for use in uncertain field conditions, but are quite expensive in comparison to the commercially available computers. Either of these solutions--control of the environment or the use of less sensitive equipment--impacts on financial considerations.

Sources of power are another great concern if computers are to be located in conventional schools in less developed countries. Many schools have no access to power utilities, and when they do, the power fluctuates more than most computers can tolerate. If there is no power utility, battery power, which is markedly more expensive, will have to be used. For most

computers, battery power is not sufficient so computers with lower power requirements will be needed. There have been several technological advances in recent years that allow computers to operate with low power requirements--bubble memory, liquid crystal displays, CMOS (Complementary Metal Oxide Semiconductor) technology, VLSI (Very Large Scale Integration) technology, and high-density DRAM (Dynamic Random Access Memory) devices. These are the technological devices that allow the production of small but powerful portable computers; although presently some of these devices are quite expensive, the price may go down considerably in the near future. In locations where there is a power utility, the power often fluctuates more than computers can tolerate; to some extent, fluctuating power can be controlled by means of surge and spike protectors, supplemented with emergency battery-operated power supplies for temporary use.

The lack of human resources is another concern. There will be need for trained operators (or for hardware and software that can be used effectively by untrained personnel), and for trained maintenance people; in most countries, both of these kinds of human resources are unavailable and will need to be developed.

Engineering advances could take care of most of the above problems. A problem that cannot be taken care of by the engineers is that of the educational quality of the programs. Some people feel that educational programs from the United States can be exported, possibly with slight adaptations. I do not see such a simple solution. Most of the programs developed

in the United States would not be suitable for use in the less developed nations. The curricula of different countries, even in ostensibly the same subjects, varies so much that most of our programs would not be acceptable to the Ministries of Education in many places. In some cases, this resistance will not be completely rational; there is much chauvinism in the defense of locally developed curricula. But in many cases, the reaction will be quite correct; the needs of the local populations are quite different from the needs of school children in the United States. The most obvious examples of this are in the areas of reading and language arts (in countries where English is not the mother tongue of the children), social studies, physical geography, music, and other topics that are highly dependent upon the culture, language, or physical and political characteristics of the country. Even elementary school mathematics, which is one of the most consistently taught subjects across national boundaries, cannot be exported in toto; slightly different algorithms are taught in different countries, arithmetic applications vary, and the sequence of instruction may be somewhat different. Differences in educational goals and methodologies may be less important at higher levels of education because there has been so much cross-fertilization of ideas and textual materials; calculus in Africa is not taught much differently than calculus in the United States, for example.

A related concern is the "style" of the programs. Many of the educational programs used in the United States have a game-like quality that is desired here for its motivational value. In other countries, education is perceived as a serious

business, and children are not encouraged by their elders to play in school. Programs that appear too game-like will not be culturally acceptable in those countries.

If the software cannot be imported from the developed nations, it will have to be developed specifically for the less developed nations. Where the financing for this will be found is problematic.

High cost is the main impediment to the use of computers in education. Even in the United States, one of the wealthiest countries in the world, few school child have instant and unlimited access to computers, not now, and not in the foreseeable future. How then can the less developed nations afford computer-based instruction?

The question should be addressed in terms of cost-effectiveness, not simply in terms of cost, and at present, I see few applications of computer-based instruction that would prove cost-effective. Even those applications that are cost-effective in the United States might not prove so in a less developed country where the salaries of teachers, the maintenance costs of school buildings, etc. are lower than in the United States.

The Future of Computer-based Instruction in LDC's

The future of anything related to computers has proved extremely difficult to predict (we were to have natural language

translators in the 60's, as I recall, and very few people at that time predicted the development and rapid acceptance of home computers). Nevertheless, I want to point out some ways in which computers might be used in education in the less developed countries in the next 10 years.

If rational decisions are made (not always true in education), the overriding concern will be with the cost-effectiveness of the applications. There are four possible application areas that might prove cost-effective.

One of these is the area in which computer-assisted instruction has proved to be cost-effective in the United States: in remedial programs for students who have fallen behind in their studies. In most of the less developed nations, these students are ignored, and they are often rapidly lost to the school system. In some few countries, however, there is concern for these students, and remedial instruction, with rather high teacher/student ratios, is supplied. If the teacher/student ratio is high enough, if the cost of teachers' salaries is substantial, and if efficient computer-based programs can be developed (or adapted), this application area might prove cost-effective.

A second, and more likely application area, is in the use of simulation programs or combined tutorial/simulation programs in science teaching to replace rather costly science laboratory equipment. The cost-effectiveness of this application will depend upon the current or planned levels of investment in

laboratory equipment, and the ability of the computer programs to provide nearly equivalent experience. There are now simulation programs in use in the United States that can provide students with experiences that are better in some ways than that they could obtain with more costly apparatus, and in ways that are safer, and more time-efficient. Physics, chemistry, and electronics are among the likely candidates, as are several areas of applied science and vocational training, such as automotive diagnosis and horticultural management.

A third area that may prove cost-effective is in higher education in courses in which there is very high teacher/student ratio or in courses for which there are no qualified teachers. These would probably be either very advanced courses or courses that cover topics, such as computer science, that have not been taught in the past. In any one university, there may be only a few students per year for courses like quantum mechanics, epidemiology, or topology. If these students have to travel to another university, perhaps in another country, to take such courses, the cost would be very high, and computer-assisted instruction might be the best solution. Because the cost of developing such courses is high, the most reasonable approach would be for the cost of development to be shared by a number of countries. To develop programs suitable for use in several countries, problems of language and differences in instructional tactics must be taken into account.

A fourth application area that is possible, although considerably more speculative, is the development of single-

purpose, microprocessor based devices. Several such devices have been developed for education; there are, for instance, small hand-held devices that deliver drill exercises in specific subjects. Because the entire mechanism of a general-purpose computer is not used, the production costs of these devices are considerably lower than for microcomputers. Although there are few available mechanisms of this type, and probably none that are suitable for direct application in other countries, the possibility for providing cost-effective instruction is high if the potential audience is large enough so that economies of scale in production can be attained.

In some of the above areas, there are programs in use in the United States that could be modified for use in other countries; some of these modifications would be substantial and therefore costly, but of course less costly than developing completely new courses. In other cases, there are no available programs, or the available programs are so unsuitable that a modification would be less advisable than developing a new course.

A detailed cost analysis should be undertaken before any decisions to implement are made; it is possible that none of the potential application areas mentioned above would be cost-effective now. But it is also possible that costs will be greatly reduced in the near future by new technological breakthroughs. What might happen, in that eventuality, is that there would be a rush to implement computer-based instruction, without adequate planning for the educational quality of the programs, and there

would then be an adverse reaction that would set back further development. Since engineering advances seem to come at a faster rate than advances in the art of teaching, it would seem that the time to plan for the future of educational uses of computers is now. Research into effective means of using microprocessors in education in the less developed countries could be undertaken now on not too great a scale so that the programmers of educational materials would not be caught unprepared when the day comes that the hardware costs are reduced to the point of acceptability.

Glossary

Central processing unit (CPU) - the heart of the computer, the part in which programmed instructions are executed

Computer-assisted instruction - used above synonymously with "computer-based" instruction

CPU - see Central processing unit

Mainframe - a large computer, like an IBM 370, as distinguished from smaller minicomputers and even smaller microcomputers

Minicomputer - a medium-sized computer, operationally similar to a mainframe computer

Microcomputer - a small computer, usually used by just one person at a time (and therefore called a "personal" computer); larger microcomputers can use time-sharing systems similar to those used on mainframe and minicomputers.

Operating system - a computer program that "manages" a computer while the computer is running; the operating system controls the operation of other programs, such as instructional programs; operating systems come in two basic types, single-user systems and multiuser (or "time-sharing") systems.

System - sometimes used as "computer system"; "computer" is sometimes used loosely to mean "computer system"; techni-

cally, the computer is only a small part of a computer system, which also comprises the operating system and various peripheral devices such as terminals, printers, disk storage devices, and modems; also see Time-sharing and Operating system.

Terminal - a device that allows a human to communicate with a computer; a terminal contains both an output device (usually a video screen) by means of which the computer can communicate with the human user and an input device (usually a keyboard) by means of which the human can communicate with the computer.

Time-sharing - a capability of operating systems that allows a number of people to use the same computer simultaneously